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**A STUDY OF CADMIUM-TIN AND ZINC-TIN  
ALLOY ELECTRODEPOSITS**

*BENNIE COHEN*

*MATERIALS LABORATORY*

*SEPTEMBER 1954*

**WRIGHT AIR DEVELOPMENT CENTER**

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*SEPTEMBER 1954*

RDO No. 611-11

WRIGHT AIR DEVELOPMENT CENTER  
AIR RESEARCH AND DEVELOPMENT COMMAND  
UNITED STATES AIR FORCE  
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

## FOREWORD

This report was prepared by the Air Research and Development Command under the Research and Development Order No. 611-11, "Electrodeposition and Electrochemical Treatments", and was administered under the direction of the Materials Laboratory, Directorate of Research, Wright Air Development Center, with Mr. Bennie Cohen acting as project engineer.

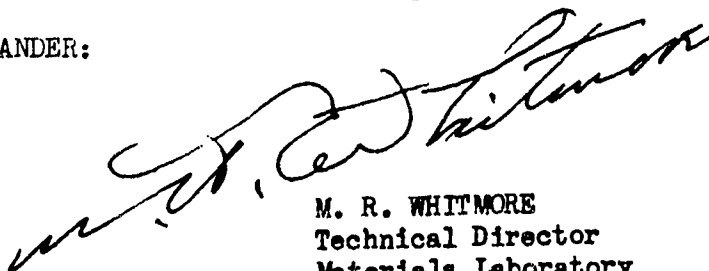
## ABSTRACT

A study has been made of cadmium-tin and zinc-tin alloy electrodeposits in the continuing efforts of the Air Force to find superior corrosion resistant coatings. The alloy systems evaluated were electrodeposited from fluoborate solutions. Cadmium was used as a basis of comparison throughout. The cadmium-tin alloy coating was found to be superior to cadmium coatings in the majority of tests performed. The cadmium-tin alloy coating was found to have excellent resistance to salt spray, jet fuels, high temperature synthetic oils, organic acid vapors, and to have very little embrittling effect on hardened steel.

## PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:



M. R. WHITMORE  
Technical Director  
Materials Laboratory  
Directorate of Research

# TABLE OF CONTENTS

	<u>Page</u>
INTRODUCTION. . . . .	1
EXPERIMENTAL WORK . . . . .	3
Test Materials . . . . .	3
Preparation of Steel Specimens Prior to Plating. . . . .	3
Cadmium-Tin Alloy Electroplating . . . . .	3
Zinc-Tin Alloy Plating . . . . .	4
Tin Plating. . . . .	6
Cadmium Plating. . . . .	6
Zinc Plating . . . . .	6
TEST SECTION. . . . .	7
Plating Thickness. . . . .	7
Salt Spray Tests . . . . .	7
Humidity Tests . . . . .	8
Oxidation-Corrosion Test in Synthetic Oil. . . . .	10
Corrosion Test in Jet Fuel . . . . .	10
Corrosion Test in Presence of Organic Acid . . . . .	13
Solderability Tests. . . . .	16
Cold Temperature Tests . . . . .	16
Hydrogen Embrittlement Tests . . . . .	16
Indicated Applications . . . . .	20
CONCLUSIONS . . . . .	23
APPENDIX I. . . . .	24
Tin Plating. . . . .	24
Cadmium Plating. . . . .	24
Zinc Plating . . . . .	24
APPENDIX II . . . . .	25
Results of Salt Spray Tests. . . . .	25
Results of Humidity Tests. . . . .	28
Results of Oxidation-Corrosion Tests . . . . .	32
Results of Corrosion Tests in Jet Fuel . . . . .	33
Results of Hydrogen Embrittlement Tests. . . . .	34
BIBLIOGRAPHY. . . . .	39



# LIST OF TABLES

## Table

	<u>Results of Salt Spray Tests</u>	<u>Page</u>
1	Cadmium (73%) - Tin (27%) Alloy Electrodeposits. . . . .	25
2	Cadmium Electrodeposits. . . . .	26
3	Zinc (62%) - Tin (38%) Alloy Electrodeposits . . . . .	27
	<u>Results of Humidity Tests</u>	
4	Cadmium (73%) - Tin (27%) Alloy Electrodeposits. . . . .	28
5	Cadmium Electrodeposits. . . . .	29
6	Zinc (62%) - Tin (38%) Alloy Electrodeposits . . . . .	30
7	Cadmium (73%) - Tin (27%) Alloy Electrodeposits on Steel Coupled to Magnesium . . . . .	31
	<u>Results of Oxidation-Corrosion Tests</u>	
8	Corrosion Medium - Spec. MIL-L-7808 Oil. . . . .	32
9	<u>Results of Corrosion Tests in Jet Fuel. . . . .</u>	33
	<u>Results of Hydrogen Embrittlement Tests</u>	
10	Test Material - 1020 Cold Rolled Wire Dia. .0625". . . . .	34
11	Test Material - 1020 Cold Rolled Wire Dia. .1235" . . . . .	37

# LIST OF ILLUSTRATIONS

<u>Figure</u>		<u>Page</u>
1	Salt Spray Tests. . . . .	9
2	Humidity Tests. . . . .	11
3	Galvanic Corrosion Tests. . . . .	12
4	Corrosion Tests in Presence of Acetic Acid Vapors. . . . .	14
5	Corrosion Tests in J-P-4 Fuel . . . . .	15
6	Cold Temperature Test . . . . .	17
7	Multiple Bend Wire Tester, H <sub>2</sub> Embrittlement Studies . . . . .	19
8	Bends to Fracture Average, Wire Diameter - .0625". . . . .	21
9	Bends to Fracture Average, Wire Diameter - .1235". . . . .	22

## INTRODUCTION

The Air Force uses numerous electroplated steel parts on its aircraft primarily for the purpose of corrosion prevention. An electrodeposit used to prevent the corrosion of steel should furnish sacrificial (cathodic) protection in order to be satisfactory.

There are only two metals capable of being electrodeposited which furnish cathodic protection to steel, zinc and cadmium. These two coatings when used in atmospheric conditions found in the greatest portion of the United States are quite satisfactory in preventing the corrosion of steel, but the Air Force employs its aircraft under many conditions in which zinc and cadmium coatings tend to deteriorate rapidly. The temperature cycle induced by flying causes condensation of moisture on the exterior and interior parts of the aircraft.

For example, past experience has shown that cadmium and zinc coatings are not entirely satisfactory in the presence of high humidity, salt atmospheres, high temperature synthetic oils, jet fuels and organic acid vapors. Past experience has also shown that cadmium plating by conventional methods is detrimental to the physical properties of steel, due mainly to hydrogen embrittlement. Effort is constantly being made to eliminate this harmful feature.

In 1946 a contract was initiated with Battelle Memorial Institute (1) to investigate electrodeposited alloys and pure metals as a substitute for zinc and cadmium as protective finishes for steel parts of aircraft. As a result of this investigation only two coatings, Cd-Sn and Zn-Sn alloys, displayed improvement over cadmium and zinc.

In 1950 the Bureau of Aeronautics, at the Naval Air Station, Pensacola, Florida began an investigation (2) to explore the possibility of developing a single protective coating for steel that would combine the mechanical protection of baked resin, the electrolytic protection of cadmium and zinc, and the non-galling characteristics of silver, tin, lead or copper. The Cd-Sn alloy system was selected as having the

best possibility of achieving the desired coating. This coating was applied by electrodepositing first tin, then cadmium, and finally alloying the two by heating. The investigation showed that the Cd-Sn alloy system had many favorable aspects. This prompted the Wright Aeronautical Corporation to develop a method of plating an alloy of cadmium and tin from a fluoborate solution (3).

Tests performed by Wright Aeronautical Corporation and later by the Naval Air Experimental Station (4) on the Cd-Sn alloy showed that it displayed corrosion resistance superior to cadmium when used as a coating for steel.

The above mentioned results were used as basis for this investigation and a major portion of this work consists of a further investigation of the cadmium-tin alloy electrodeposits. The zinc-tin alloy was tested only for its resistance to corrosion in salt spray and in high humidity.

The Cd-Sn alloy was tested for resistance to corrosion in salt spray and high humidity. The alloy was tested for resistance to corrosion in high temperature synthetic oils and in jet fuels, in order that possible use may be made of it in the lubricating and fuel systems of aircraft.

Cadmium electrodeposits are attacked by organic acid vapors, such as occur from insulation and "wrinkle" finishes in electronic equipment and from unseasoned wood used in packaging. The Cd-Sn alloy was tested for its resistance to an organic acid vapor.

The Cd-Sn alloy was also tested for solderability, for susceptibility to tin-disease at cold temperature, and for embrittling effect upon steel.

## EXPERIMENTAL WORK

### Test Materials

The steel used in this investigation for the preparation of the 2" X 4" corrosion test panels was Gage 11 flat stock of SAE 1020 steel with an average surface finish of 6 microinches (R. M. S.). The magnesium alloy used for corrosion test panels was Dow FS-1 sheet with a dichromate (Dow 7) finish. The aluminum alloy used for corrosion test panels was bare 24S-T3. The magnesium and aluminum alloy panels were used only in galvanic corrosion tests.

The one inch square test specimens used in several tests consisted of mild steel. The wires used in the hydrogen embrittlement tests were SAE 1020 steel with diameters of .0625" and .1235". All electrodeposited specimens in this investigation have steel as the basis metal.

### Preparation of Steel Specimens Prior to Plating

All steel corrosion specimens were given the following treatments prior to electroplating.

- (1) Degrease in trichloroethylene
- (2) Rinse
- (3) Alkaline clean (cathodically)
- (4) Rinse
- (5) Treat anodically in a solution consisting of 66%  $\text{H}_2\text{SO}_4$  (20% by volume) — 85%  $\text{H}_3\text{PO}_4$  (80% by volume) at 100 amps./sq. ft. for 3 minutes at room temperature.
- (6) Rinse
- (7) Alkaline clean (anodically)
- (8) Rinse
- (9) HCl (50%) pickle for 1 minute
- (10) Rinse
- (11) Electroplate immediately

### \*Cadmium-Tin Alloy Electroplating

Steel specimens were electroplated with Cd-Sn alloy from the directions given by Scott and Gray (3). Two exceptions were made; sodium p-phenol sulfonate was substituted for phenol sulfonic acid and gelatin was substituted for processed protein powder.

\*U. S. Patent-2609338 (1952)

#### Composition to Make 1 Liter

Cadmium fluoborate (43%)	296 cc.
Stannous fluoborate (46.1%)	67.2 cc.
Boric acid	20 grams
Ammonium fluoborate	50 grams
Fluoboric acid (43%)	58.5 cc.
Sodium p-phenol sulfonate	2.0 grams
Gelatin	2.0 grams

Plating was accomplished in a six liter glass receptacle.

Individual tin and cadmium anodes with a surface area ratio of 3:1 were used. It was necessary to bag the anodes to prevent contamination of the bath. Separate anodic circuits were employed so that equal current could be passed through the tin and cadmium anodes. An electrodeposit was obtained containing approximately 73% cadmium-27% tin. This composition was used in all tests. The alloy electrodeposits were analyzed by the polarographic method.

The pH of the bath was maintained at 3.0; a cathode current density of 27 amps/sq. ft. was used, and the temperature was controlled by means of a water bath at 27°C  $\pm$  0.2°C. Agitation was provided by means of an air stirrer.

The Cd-Sn alloy plate obtained from this bath was ductile, adherent, and silvery-white in appearance. The plate was easily given a lustrous appearance by hand buffing with a soft cloth. This was done on all test specimens.

#### Zinc-Tin Alloy Plating

A zinc-tin alloy containing approximately 70% zinc was desired in order to compare it to the Cd-Sn plate. The Zn-Sn alloy deposited from a cyanide-stannate bath developed by the Tin Research Institute (5) in England has a nominal composition of 80% tin and 20% zinc. This was the type bath used by Battelle Memorial Institute under Contract AF 33(038)-8750 (1). It was thought that an alloy containing approximately 70% zinc could be obtained from a fluoborate bath similar to the process used in obtaining the Cd-Sn alloy. The following bath

was tried in an attempt to electrodeposit such an alloy. Plating was done in a two liter glass receptacle.

Composition to Make 1 Liter

Zinc fluoborate (41%)	288.0 cc.
Stannous fluoborate (46.1%)	65.8 cc.
Boric acid	20 grams
Ammonium fluoborate	50 grams
Fluoboric acid (43%)	60 cc.
Gelatin	2 grams
Sodium p-phenolsulfonate	2 grams

This bath was compounded the same way as the Cd-Sn bath except that zinc fluoborate was substituted for cadmium fluoborate. Individual tin and zinc anodes were used with a surface area ratio of 3:1. A separate circuit was used for each type anode in order to get equal current distribution of the anodes.

The anodes were bagged to prevent contamination of the bath. A cathode current density of 27 amps sq./ft. was used, the temperature maintained at  $27^{\circ}\text{C} \pm 0.2^{\circ}\text{C}$  and the pH adjusted to 1.0 with  $\text{NH}_4\text{OH}$ . A dark, crumbly, brittle plate was obtained from this bath. The pH was raised to 2.0 with  $\text{NH}_4\text{OH}$ . The resulting plate was metallic but brittle and somewhat pitted. The pH was raised to 2.5 with  $\text{NH}_4\text{OH}$ , and 2 grams/liter of caffeine, 1 gram/liter of gelatin, and 1 gram/liter of sodium p-phenolsulfonate were added. The plate now obtained was ductile and adherent, with a dull silvery appearance which darkened upon rinsing. By hand buffing with a soft cloth, a lustrous plate was obtained.

The bath used for obtaining the Zn-Sn alloy electrodeposits employed in this investigation was as follows:

Composition to Make 1 Liter:

Zinc fluoborate (41%)	288.0 cc.
Stannous fluoborate (46.1%)	65.8 cc.
Boric acid	20 grams
Ammonium fluoborate	50 grams
Fluoboric acid (43%)	60 cc.
Gelatin	3 grams
Caffeine	2 grams
Sodium p-phenolsulfonate	3 grams

The alloy obtained contained approximately 62% zinc-38% tin. The alloy electrodeposits were analyzed by the polarographic method.

#### Tin Plating

The tin plating used in this investigation was obtained from a fluoborate bath. The composition of the solution and the conditions for plating are given in Appendix I.

#### Cadmium Plating

The cadmium plating used in this investigation was obtained from a cyanide type bath. The composition of the solution and the conditions for plating are given in Appendix I.

#### Zinc Plating

The zinc plating used in this investigation was obtained from a cyanide type bath. The composition of the solution and the conditions of plating are given in Appendix I.



## TEST SECTION

### Plating Thickness

The thickness of all electrodeposits on flat specimens was determined by means of the Magne-Gage, manufactured by the American Instrument Co., which had been previously calibrated by the National Bureau of Standards. Three thickness determinations were made on each panel; one being made at each end and one at the center. The plating thickness reported for each panel is an average of these three determinations. The thickness of coatings on wire specimens was determined by means of a micrometer.

### Salt Spray Test

The Cd-Sn and Zn-Sn alloys were exposed in a salt fog corrosion test cabinet manufactured by the Industrial Filter and Pump Mfg. Co., Type CA-1 and operated in accordance with Federal Specification QQ-M-151a. De-ionized water was used throughout and the pH of the salt solution maintained between 6.5 and 7.2. The concentration of the salt solution was kept at 20% by wgt. and the temperature of the cabinets maintained at between 92°F and 97°F. The specimens were suspended vertically in the salt spray cabinet by means of glass hooks. Cadmium plated specimens were used as controls. A tabulation of results is given in Appendix II.

The Cd-Sn alloy electrodeposit had a phenomenal resistance to corrosion in the salt spray. It was far better than cadmium or the zinc-tin alloy used in this investigation. The remarkable feature about the Cd-Sn alloy was that once pin point corrosion did occur on the base metal, the tendency for the corrosion to spread was very low. Cadmium in comparison would allow rapid corrosion of the base metal after the initial corrosion had started.

The Zn-Sn alloy electrodeposit was completely covered with white corrosion products in a short time. The 960 hours obtained before initial corrosion of the base metal is misleading since the base metal was protected by the matting corrosion products of the zinc which would be mostly removed under ordinary wear received in

service use. Furthermore, for many mechanism applications, these heavy white corrosion products will interfere with operation. Results of salt spray test are shown in Figure 1.

#### Humidity Test

The Cd-Sn and Zn-Sn alloy coatings were tested for their ability to prevent rusting of steel in hot humid air. The Cd-Sn alloy coating was also tested for its galvanic effect on aluminum and magnesium alloys.

The testing was done in a humidity corrosion test cabinet, manufactured by the Industrial Filter and Pump Mfg. Co., Type CA-1. Deionized water was used throughout with the temperature maintained at 95°F  $\pm$  2°F. The air was maintained at 100% saturation. Specimens were suspended in the cabinet by means of glass hooks. Cadmium plated specimens were used as controls.

A wet-dry cycle was used for all the humidity corrosion testing. For two hours each day, all specimens were removed from the cabinet and hung in front of a heater fan which dried the specimens and kept them warm until placed back into the cabinet. This cycle was omitted for two days a week and the panels during that period remained in the humidity cabinet. A tabulation of results of humidity tests is given in Appendix II.

The Cd-Sn alloy electrodeposit had very good resistance to corrosion in the high humidity tests and showed only traces of white corrosion products after 3182 hours. The cadmium coatings, although badly discolored, still protected the base metal from corrosion for the same length of time. The Zn-Sn alloy coatings were inferior to the cadmium and Cd-Sn alloy coatings in resistance to corrosion in high humidity surroundings.

There was extensive corrosion of magnesium alloy, treated with Dow #7, when coupled to both the Cd-Sn alloy and cadmium coated panels. No distinction could be made between the two coatings as to their effect on magnesium alloy. The

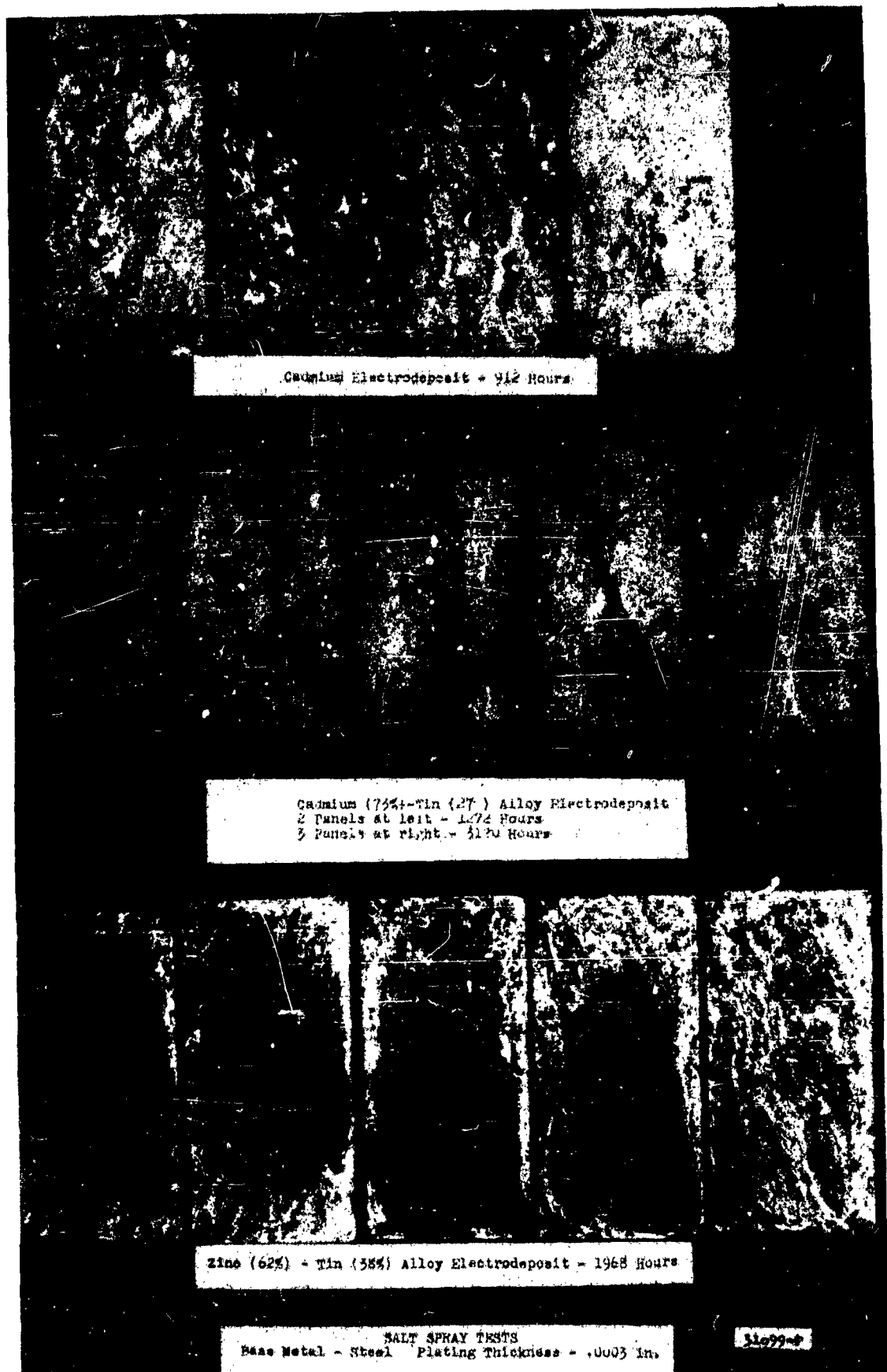


Figure 1

24S-T3 aluminum alloy when coupled to steel panels coated with Cd and Cd-Sn alloy displayed no appreciable corrosion after 1224 hours. The galvanic effect of cadmium and Cd-Sn alloy coatings when coupled to magnesium and aluminum were equal for all practical purposes. Results of humidity tests are pictured in Figures 2 and 3.

#### Oxidation-Corrosion Test in Synthetic Oil

The Cd-Sn alloy coatings were tested for their ability to resist corrosion in synthetic oils at high temperatures using cadmium coatings as controls. The plated specimens were immersed in oil conforming to Specification MIL-L-7808 which was maintained at a temperature of 347°F. Air was bubbled through the oil at a rate of 5 liters/hour. The weight losses of the Cd and Cd-Sn alloy coatings on steel were obtained at the end of 72 and 144 hours. A tabulation of results of tests is given in Appendix II.

The MIL-L-7808 oil used in these tests was quite corrosive to cadmium in some cases, while in others, the oil displayed no corrosive effect on the cadmium. The corrosion of the cadmium occurred in scattered areas, being completely removed from the base metal in those areas. No sound explanation could be given as to why some of the cadmium electrodeposits failed and some did not as all were plated under the same conditions.

The Cd-Sn electrodeposits were not significantly corroded by the oil used in these tests and appeared to be superior to cadmium for use on steel in oxidation-corrosion resistance to synthetic oil at high temperatures. Test specimens are pictured in Figure 4.

#### Corrosion Test in Jet Fuel

The Cd-Sn alloy coatings were tested for their ability to resist corrosion in jet fuels containing mercaptan sulfur, using cadmium coatings as controls. The specimens were immersed in JP-4 fuel, conforming to Specification MIL-F-5624A, but containing 0.017% mercaptan sulfur by weight. A slight amount of water was added to give a water saturated fuel layer. Some of the specimens were totally

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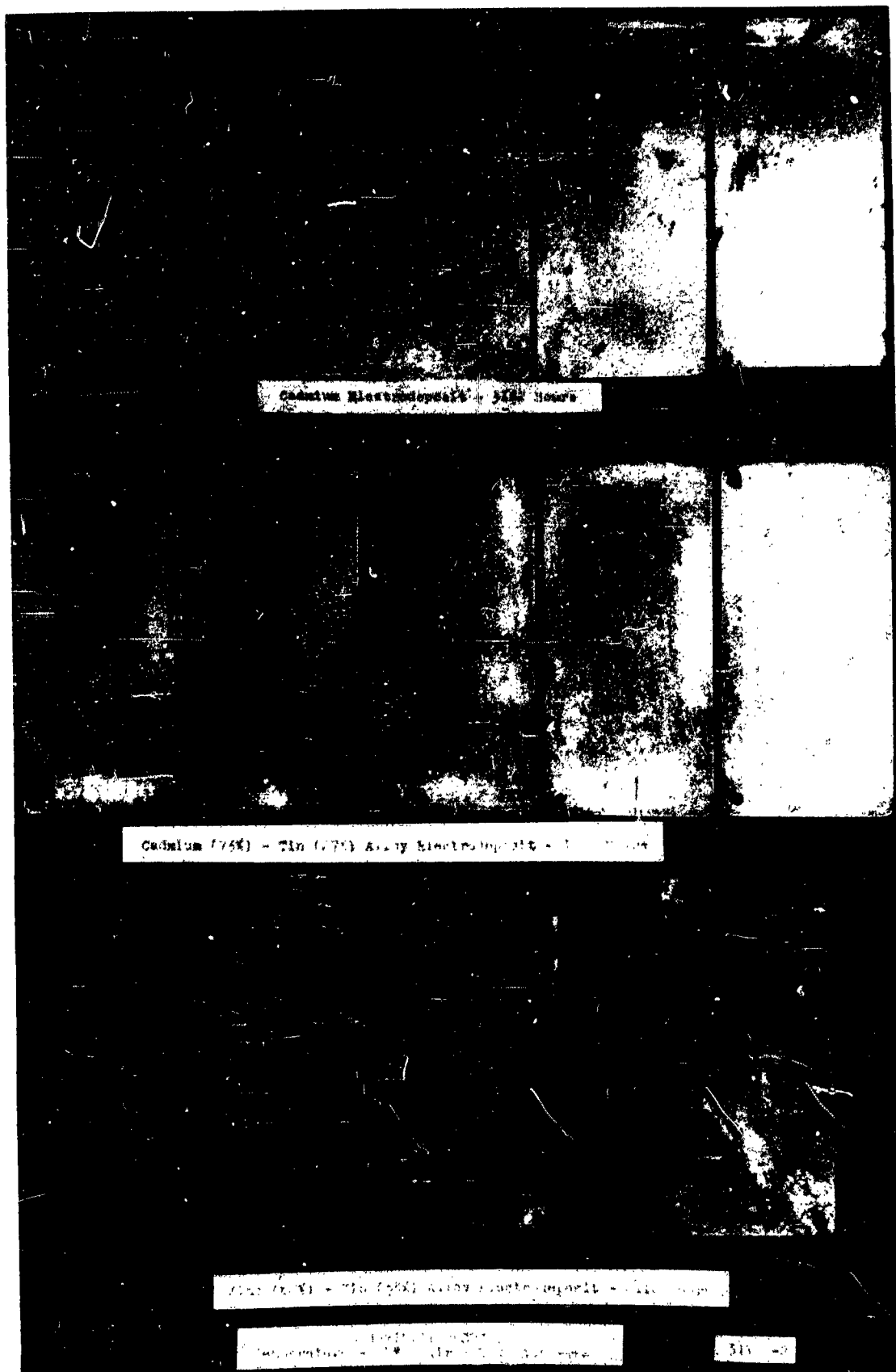


Figure 2

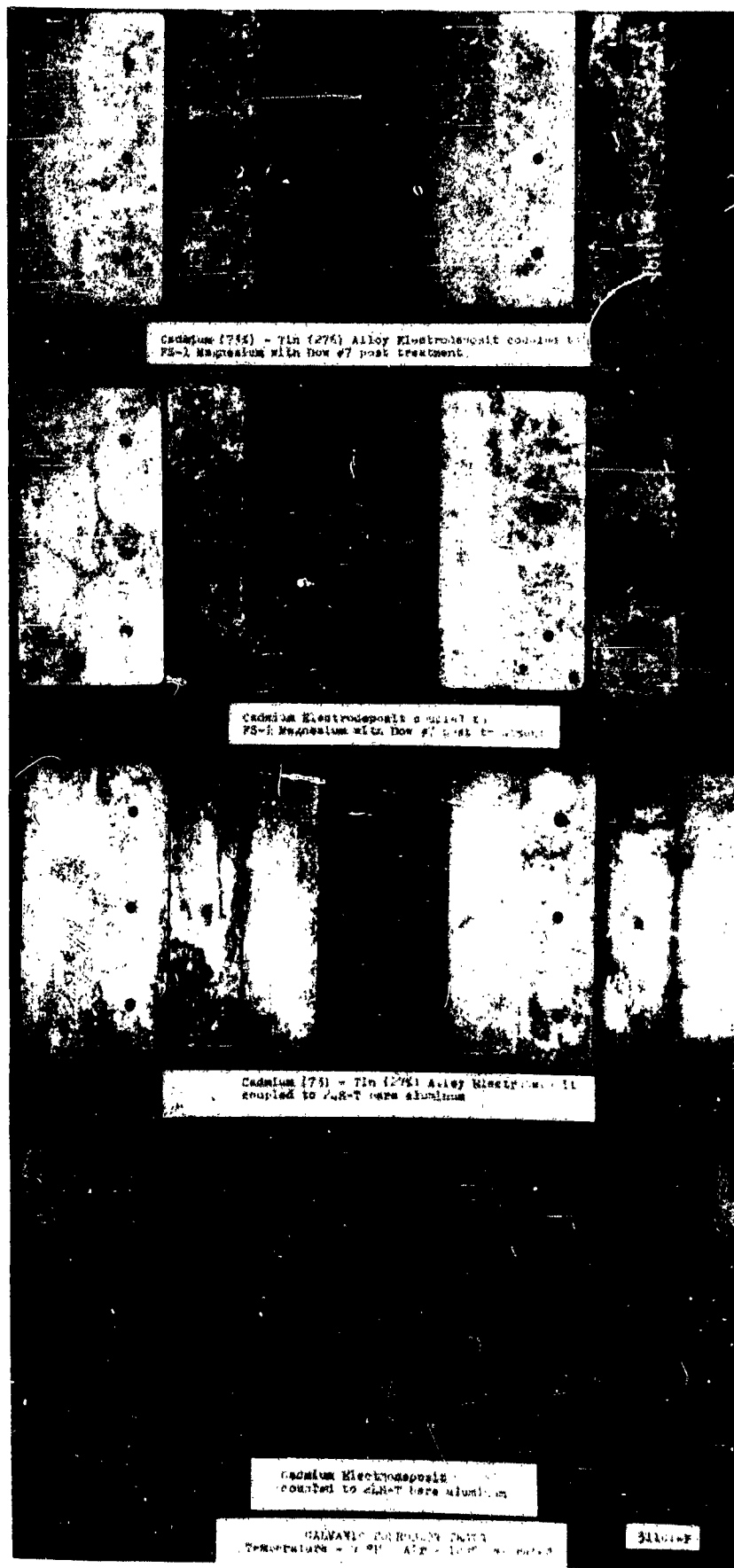


Figure 3

immersed in the fuel and some were only partially immersed. The test cells consisted of large glass jars which were capped and maintained at a constant temperature of 95°F. The specimens were weighed periodically to determine weight losses.

The JP-4 jet fuel containing .017% mercaptan sulfur by weight was considerably more corrosive to cadmium coatings than the Cd-Sn alloy coatings. Test specimens are pictured in Figure 4. At the end of 84 days exposure the Cd-Sn alloy coatings had an average weight loss of 2.5 mg./sq. in. while the Cd coatings had an average weight loss of 25 mg./sq. in. and displayed considerable signs of corrosion. A comparison of results is shown by means of a graph in Figure 5.

#### Corrosion Test in Presence of Organic Acid

Acetic acid, an ingredient of unseasoned wood, was used to test the resistance of Cd-Sn alloy electrodeposits to organic vapors. Cadmium electrodeposits were used as controls.

The Cd-Sn plated steel specimens and Cd plated steel specimens were placed over a 5% and a 1% aqueous solution of acetic acid by volume. The test cells consisted of capped glass jars which were maintained at a temperature of 95°F. The specimens were checked at frequent intervals for corrosion.

The cadmium electrodeposit and steel base metal in the presence of a 5% aqueous solution of acetic acid was completely corroded in 48 hours, but the Cd-Sn electrodeposit under the same conditions showed no sign of corrosion.

The cadmium electrodeposit and steel base metal in the presence of a 1% aqueous solution of acetic acid was completely corroded in 144 hours, but the Cd-Sn electrodeposit under the same conditions showed no sign of corrosion. These specimens are pictured in Figure 4. As a result of these tests it was definitely shown that cadmium coatings are severely corroded by the vapors from aqueous solutions of acetic acid while the Cd-Sn alloy coatings are not. This same trend could probably be expected from other organic acid vapors, for example those produced by insulation and "wrinkle" finishes.

Cadmium (73%) - Tin (27%) Alloy Electrodeposit

Cadmium Electrodeposit

CORROSION TEST IN JET FUEL  
Exposure Time - 84 Days Temperature - 95°F

Cadmium Electrodeposit

Cadmium (73%) - Tin (27%) Alloy Electrodeposit

OXIDATION-CORROSION TEST IN MIL-L-7808 OIL  
Temperature - 347°F Time - 72 Hours

Cadmium (73%) - Tin (27%) Alloy Electrodeposit

Cadmium Electrodeposit

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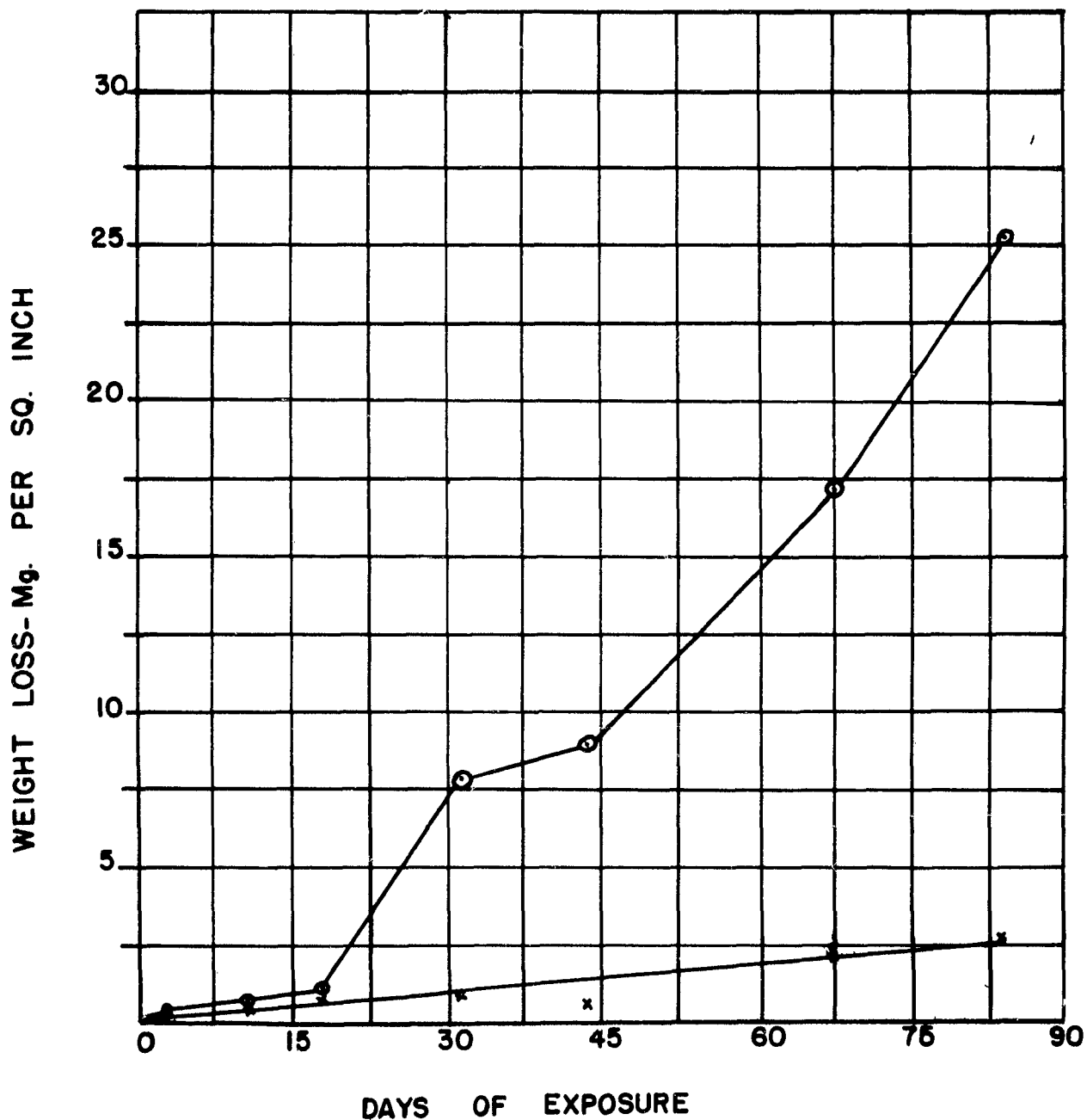
CORROSION TEST IN PRESENCE OF ACETIC ACID VAPORS

Figure 4



FIGURE 5

CORROSION TEST IN JP-4 FUEL  
X Cd(73%)-Sn(27%) ALLOY ELECTRODEPOSIT  
O Cd ELECTRODEPOSIT  
EACH POINT IS AN AVERAGE OF 4 SAMPLES  
TEMPERATURE - 95° F



### Solderability Tests

The Cd-Sn and Zn-Sn alloy coatings were tested for solderability by determining the ability of the coating to be wetted by solder. The solder used was 50% Sn-50% Pb with no flux. Cadmium and zinc coatings were used as controls. All the coatings were allowed to age for five months before these tests were run.

Both the cadmium and Cd-Sn alloy coatings were easily wetted by the solder and therefore could be satisfactorily soldered. The zinc and zinc-tin coatings had very poor wetting characteristics which would cause them to be difficult to solder.

It has been reported in the literature (6) that the tin-zinc alloy containing 80% tin has excellent soldering characteristics. The zinc-tin alloy tested above contains only 38% tin, probably accounting for its poor soldering characteristics.

### Cold Temperature Tests

White tin will transform into grey tin at low temperatures causing complete loss of the usefulness of the tin coatings. The Cd-Sn coatings were tested to see if the tin portion of the alloy had the tendency to transform into grey tin. The Cd-Sn alloy coatings and the tin coatings were inoculated with grey tin, by spreading grey tin powder on the surface, and were then placed in a cold box maintained at a temperature of -50°C.

The Cd-Sn alloy coatings were not affected by cold temperature with respect to the tin in the alloy transforming from white to grey tin. The tin coatings in this investigation completely disintegrated in 78 days into powdery grey tin. The transformation was a gradual process and was dependent upon time. These panels are pictured in Figure 6.

### Hydrogen Embrittlement Tests

The fluoborate type electroplating bath operates at approximately 100% cathode current efficiency. As a result of this, there should be very little, if any embrittlement of steel being electroplated with the Cd-Sn and Zn-Sn alloys. Embrittlement is a serious problem when plating steel with cadmium from the

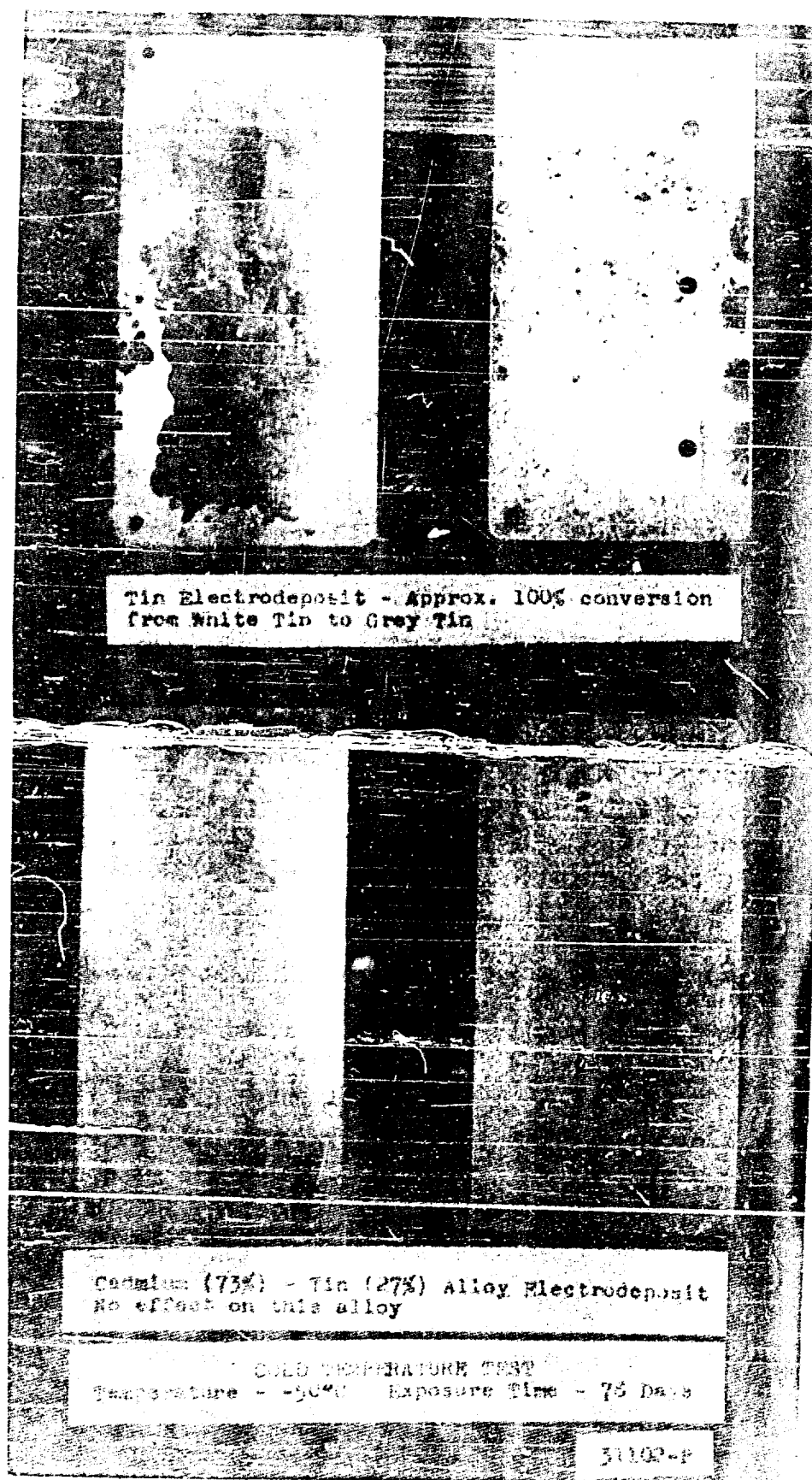


Figure 6

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cyanide type bath.

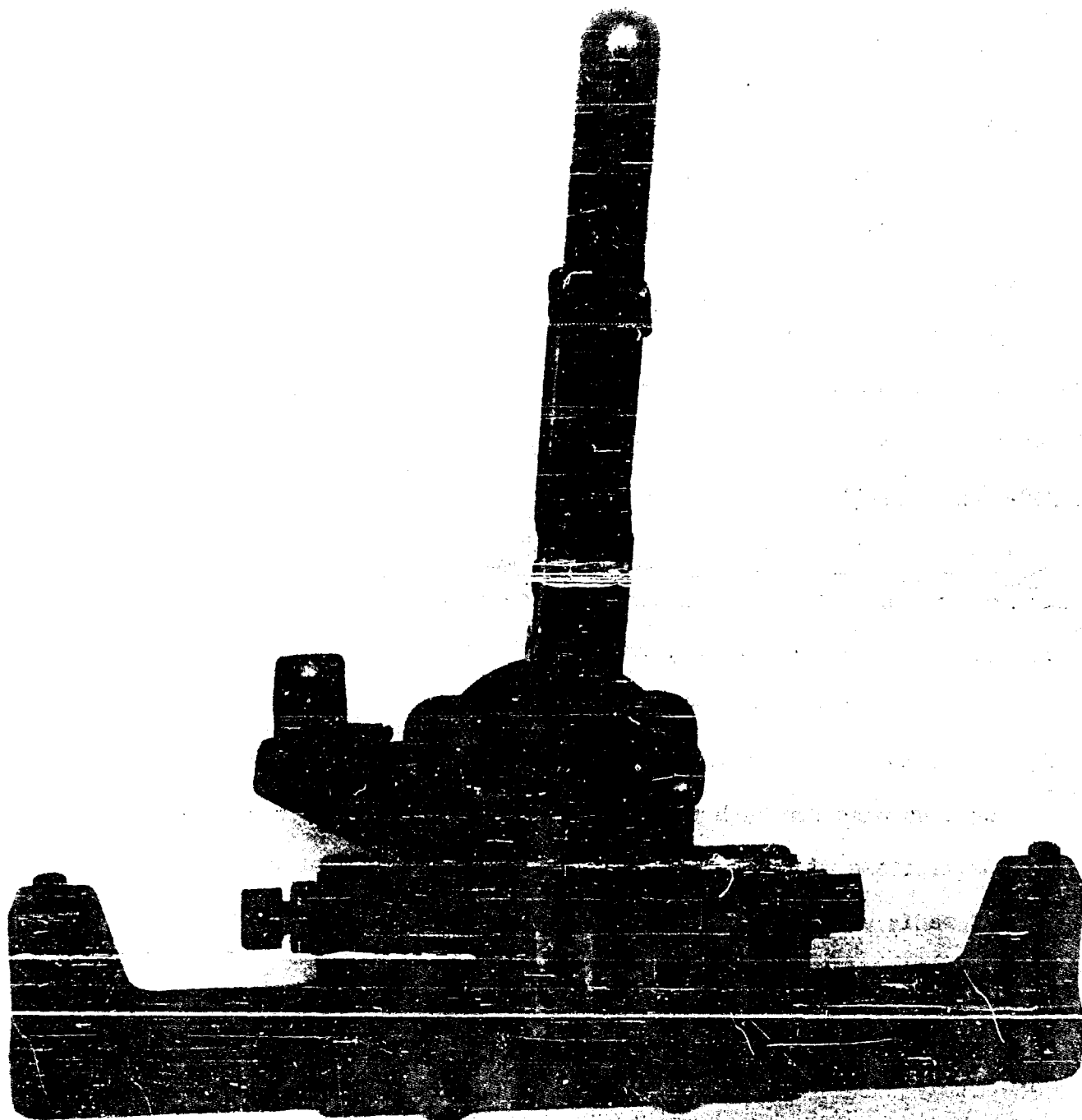
Bend tests were made on cold drawn SAE 1020 steel wires, .0625" and .1235" diameter, which had been plated with the Cd-Sn alloy. Plated and unplated wires were used as controls to determine the extent of embrittlement caused by electroplating from a fluoborate solution as compared to the embrittlement caused by plating cadmium from a cyanide bath.

A multiple bend wire tester, pictured in Figure 7, was used in evaluating the extent of embrittlement. This instrument was constructed at this Center and can test wires up to 1/4 inch in diameter. The wire is clamped into position at the bottom and inclosed in a slot to fit the wire at the top. Starting from the vertical position the wire is bent 90° to the horizontal, returned to the vertical position, bent 90° to the horizontal in the opposite direction, and then returned to the vertical. This consists of one cycle which is equivalent to four bends, or each 90° bend is counted as one bend. The wires were bent at a constant rate by hand around a die having a radius of 3/16" until fracture in the wire occurred. The rate of bending was checked closely by a stop watch. Time of testing was 10 minutes after plating where noted.

Checks were made on the extent of embrittlement of steel during the cleaning and pickling cycles in order to get the true amount of embrittling due to the electroplating processes. Results of tests are given in Appendix II.

Excellent reproducibility of results was obtained using the bend tester described in this investigation. A sufficient spread of the number of bends required to fracture occurred with the SAE 1020 cold drawn steel wire to differentiate the degree of embrittlement of the steel.

It was shown that no or relatively little embrittlement occurred during the cleaning and pickling cycle under the conditions used. Therefore any final embrittlement occurring was a result of the plating operation itself. There was considerable embrittlement of steel during the plating of cadmium from a cyanide solution as was expected by previous experience and from data in the literature.



Multiple Bend Wire Tester  
For Embrittlement Studies

Figure 7

There was no or relatively little embrittlement of steel as the result of plating steel with Cd-Sn alloy from the fluoborate solution as was expected since this type bath operates at approximately 100% cathode current efficiency.

The data obtained indicates that steel should be cleaned anodically in the alkaline cleaner instead of cathodically to prevent hydrogen embrittlement. By anodically cleaning the steel in the alkaline cleaner no embrittlement occurred and in some instances the steel was more ductile after cleaning than before any treatment had been used. This can be accounted for by assuming that the anodic cleaning process actually removed some of the hydrogen from the steel that was implanted there by the manufacturing processes. A graphical comparison of the results of the hydrogen embrittlement tests is given in Figures 8 and 9.

#### Indicated Applications

From the test data presented in this report, it is believed that Cd-Sn plating may be useful in the following applications:

1. Nuts and bolts where only small thicknesses of plating are possible because of fit interference.
2. Items made of steel where soldering with rosin core solder is necessary such as cans for bath tub type condensers.
3. Small items of hardware inside of plastic instrument cases and inside of radio equipment.
4. Parts in contact with fuel.
5. Parts in contact with hot synthetic oil.
6. Hardened steel parts where hydrogen embrittlement is a problem.

Results of  
Hydrogen Embrittlement Tests  
Wire Diameter - .0625"

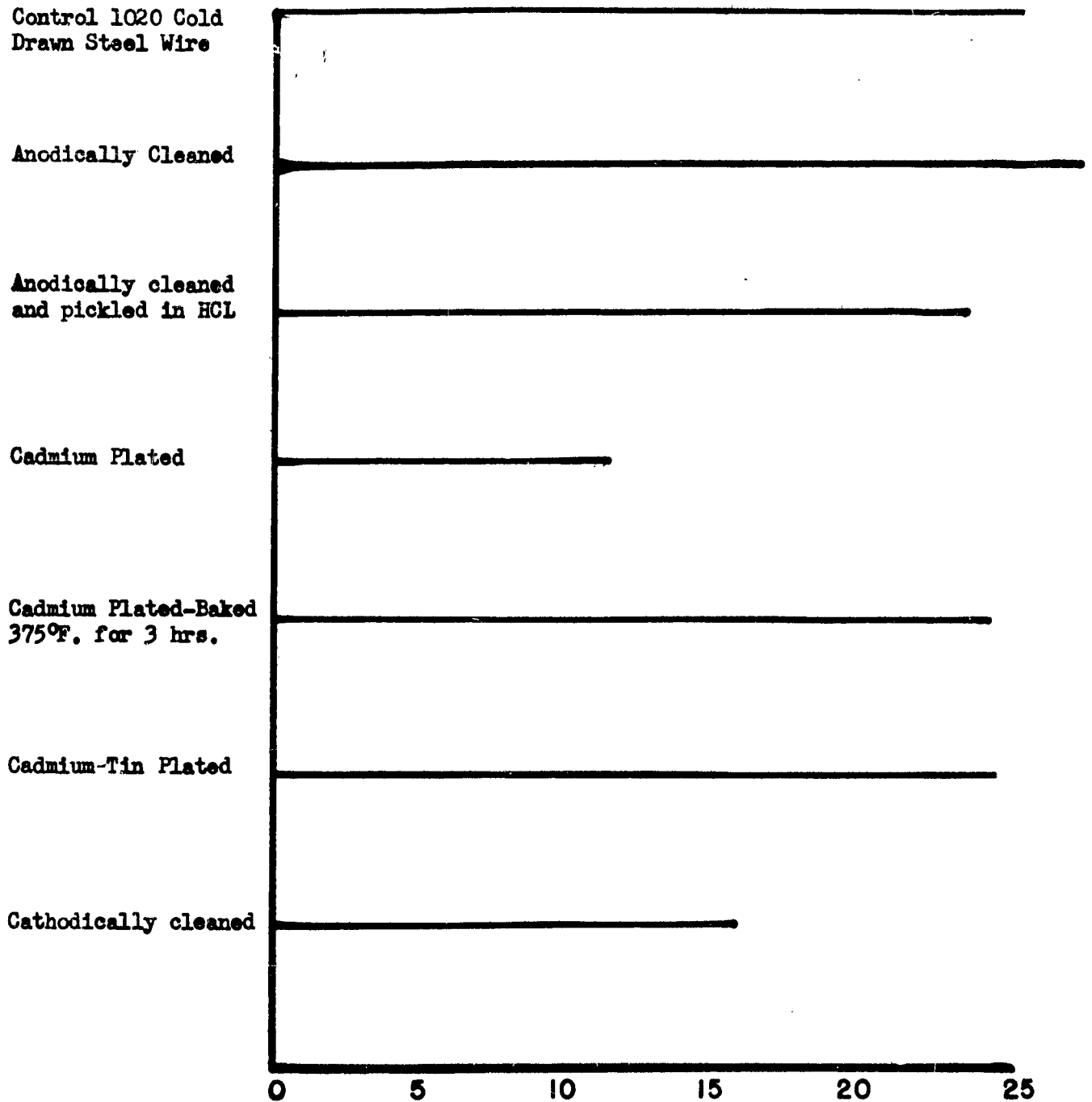


Figure 8  
Bends to Fracture Average

Results of  
Hydrogen Embrittlement Tests  
Wire Diameter - .1235

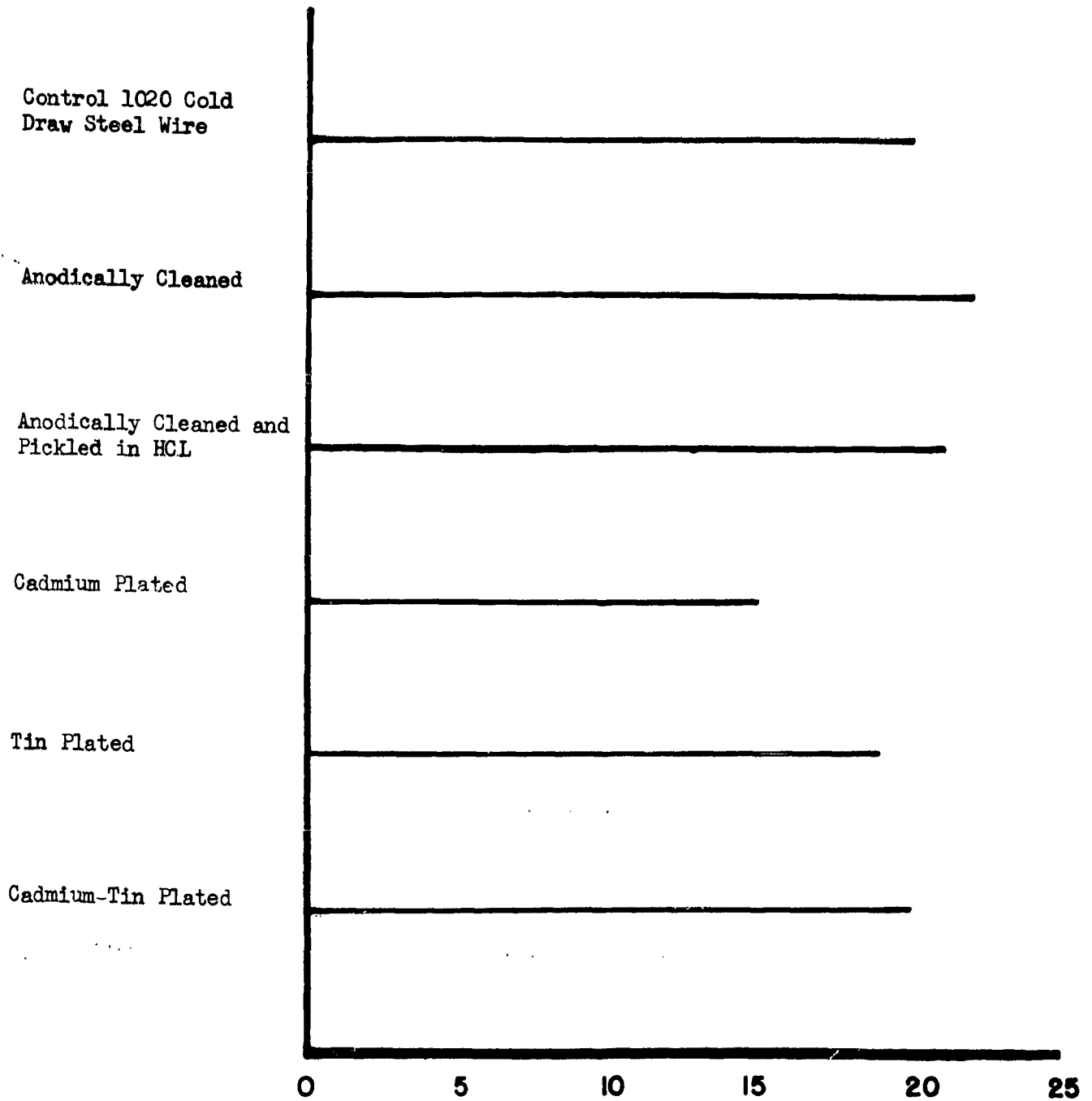


Figure 9

WADC TR 54-240

Bends to Fracture-Average



## CONCLUSIONS

The direct conclusions to be drawn from the results of the individual tests are summarized below. These conclusions should not be construed as final and should only be used as guides to obtain applications where needed. A final conclusion cannot be drawn until each general application is service tested.

1. The Cd-Sn alloy coating is far superior to cadmium in salt atmosphere.
2. The Cd-Sn alloy coating is slightly better than cadmium coatings in high humidity conditions.
3. The Cd-Sn alloy and cadmium coatings are equal in galvanic effect upon aluminum and magnesium alloy in high humidity conditions.
4. Zn-Sn (62% - 38%) alloy coatings were inferior to both cadmium and Cd-Sn alloy coatings for all tests performed on this alloy.
5. The Cd-Sn alloy coating is superior to cadmium coating with respect to resistance to corrosion in jet fuels containing mercaptans.
6. The Cd-Sn alloy coating is superior to cadmium coating with respect to corrosion in high temperature synthetic oils.
7. The Cd-Sn alloy coating as electrodeposited from a fluoborate solution has a relatively small embrittling effect on steel, due to hydrogen, as compared to cadmium plated from a cyanide solution.
8. The tin in the Cd-Sn electrodeposit is not converted from white tin to grey tin at cold temperatures.
9. The Cd-Sn alloy coating can be easily soldered by means ordinarily employed for soldering cadmium.
10. The Cd-Sn alloy coating is superior to cadmium coatings for resistance to corrosion in the presence of the vapors from aqueous solutions of acetic acid. This characteristic should be similar for other organic acid vapors.

## APPENDIX I

### Tin Plating

The tin-coated panels were plated from the following solution:

HF (42%) - 78 g./l.  
Sn(BF<sub>4</sub>)<sub>2</sub> (47%) - g./l.  
Gelatin - 6 g./l.  
Beta Naphthol - 1 g./l.  
Temperature - 80°F  
Current - 27 amps./sq. ft.  
Anodes - Tin

### Cadmium Plating

The cadmium coated panels were plated from the following solution:

NaCN - 135 g./l.  
CdO - 30 g./l.  
ROHCO 20 XL Brightener - 7.5 g./l.  
Temperature - 80°F  
Current - 36 amps./sq. ft.  
Anodes - Cadmium balls

### Zinc Plating

The zinc coated panels were plated in the following solution:

ZnCN - 60 g./l.  
NaCN - 37.5 g./l.  
NaOH - 82.5 g./l.  
Na<sub>2</sub>S - .8 g./l.  
Temperature - 80°F  
Current - 27 amps./sq. ft.  
Anodes - Bagged Zinc

Solution purified by zinc dust treatment prior to use.

# APPENDIX II

Table 1

## Results of Salt Spray Tests

Cadmium (73%) -Tin (27%) Alloy Electrodeposit

Base Metal - SAE 1020 Steel

Plating Thickness given in Inches

Hours of Exposure	*Panel Numbers				
	1	2	3	5	6
	Plating Thickness				
	.00021	.00025	.00025	.00024	.00025
72	Initial White Corrosion Products				
120			Initial White Corrosion Products		Initial White Corrosion Products
292		Initial White Corrosion Products			
336	Pin Point Corrosion of Base Metal	No corrosion of base metal	No corrosion of base metal	No corrosion of base metal	No corrosion of base metal
1056	Same	Pin point corrosion of base metal	Pin point corrosion of base metal	Pin point corrosion of base metal	Pin point corrosion of base metal
1272	Same	Same and removed	Same	Same	Same and removed
2616	Slight advance of isolated spots		Slight advance of isolated spots	Slight advance of isolated spots	
3120	Same		Same	Same	

\*These panels are shown in Figure 1.

APPENDIX II  
Table 2

Result of Salt Spray Tests

Cadmium Electrodeposit

Base Metal SAE 1020 Steel

Plating Thickness Given in Inches

Hours of Exposure	*Panel Numbers			
	4	12	13	14
	Plating Thickness			
	.00020	.00021	.00021	.00020
120	Initial White Corrosion	Initial White Corrosion		
144	Same	Same	Initial White Corrosion	Initial White Corrosion
168		Initial Corrosion of Base Metal		
240	Initial Corrosion of Base Metal	Advanced Corrosion of Base Metal in 1 Area	Initial Corrosion of Base Metal	Initial Corrosion of Base Metal
312	Slight Advance	Slight Advance	Slight Advance	Slight Advance
504	Advancing	Advancing	Advancing	Advancing
912	Corroding in Large Isolated Spots	Wide Spread Corrosion	Wide Spread Corrosion	Wide Spread Corrosion

\*These panels are shown in Figure 1.

APPENDIX II  
Table 3

Result of Salt Spray Tests

Zinc (62%) - Tin (38%) Alloy Electrodeposit

Base Metal SAE 1020 Steel

Plating Thickness Given in Inches

Hours of Exposure	*Panel Numbers				
	61	62	63	64	65
	Plating Thickness				
	.00028	.00028	.00031	.00029	.00037
48	Severe White Corrosion	Severe White Corrosion	Severe White Corrosion	Severe White Corrosion	Severe White Corrosion
480	Same	Same	Same	Same	Same
960	Initial Corrosion of Base Metal	Same	Initial Corrosion of Base Metal	Same	Same
1488	Slight Ad- vance	Initial Corrosion of Base Metal	Slight Ad- vance	Initial Corrosion of Base Metal	Initial Corrosion of Base Metal
1968	All coatings are severely corroded, fragile, and have little ad- herence even though the steel base metal is only slightly corroded.				

\*These panels are shown in Figure 1.

APPENDIX II  
Table 4

Results of Humidity Tests

Cadmium (73%) - Tin (27%) Alloy Electrodeposit

Base Metal SAE 1020 Steel

Plating Thickness Given in Inches

Hours of Exposure	*Panel Numbers				
	21	22	23	24	50
	Plating Thickness				
	.00029	.00030	.00026	.00025	.00045
96	No Corrosion	No Corrosion	No Corrosion	No Corrosion	No Corrosion
312	"	"	"	"	"
1032	"	"	"	"	"
1776	Slight White Corrosion	Slight White Corrosion	Slight White Corrosion	Slight White Corrosion	Slight White Corrosion
2510	Same	Same	Same	Same	Same
3182	There was no corrosion of the base metal.				

\*These panels are shown in Figure 2.

APPENDIX II  
Table 5

Results of Humidity Tests

Cadmium Electrodeposits

Base Metal - SAE 1020 Steel

Plating Thickness Given in Inches

Hours of Exposure	*Panel Numbers				
	35	36	37	38	39
	Plating Thickness				
	.00020	.00026	.00025	.00022	.00022
192	No Corrosion	No Corrosion	No Corrosion	No Corrosion	No Corrosion
312	Scattered Black Dis- coloration of Cadmium	Scattered Black Dis- coloration of Cadmium	Scattered Black Dis- coloration of Cadmium	Scattered Black Dis- coloration of Cadmium	Scattered Black Dis- coloration of Cadmium
1032	"	"	"	"	"
1776	"	"	"	"	"
2510	"	"	"	"	"
3182	"	"	"	"	"

There was no corrosion of the base metals.

---

\*These panels are shown in Figure 2.

APPENDIX II  
Table 6

Results of Humidity Tests

Zinc (62%) - Tin (38%) Alloy Electrodeposit

Base Metal SAE 1020 Steel

Plating Thickness Given in Inches

Hours of Exposure	*Panel Numbers		
	66	67	68
	Plating Thickness		
	.0003	.0003	.0003
144	No Corrosion	No Corrosion	No Corrosion
168	Initial White Corrosion	Initial White Corrosion	Initial White Corrosion
360	Advancing Slowly	Advancing Slowly	Advancing Slowly
696	"	"	"
1440	"	"	"
1680	Plate Severely Corroded in Isolated Spots	Plate Severely Corroded in Isolated Spots	Plate Severely Corroded in Isolated Spots
2112	No Corrosion of Base Metal	No Corrosion of Base Metal	No Corrosion of Base Metal

\*These panels are shown in Figure 2.



APPENDIX II  
Table 7

Results of Humidity Tests

Cadmium (73%) - Tin (27%) Electrodeposit  
on

Steel Coupled to Magnesium

Corrosion noted only at interface.

Hours of Exposure	*Panel Numbers								
	2			8			52		
48	5%	Mg	Corroded	10%	Mg	Corroded	5%	Mg	Corroded
144	10%	"	"	10%	"	"	5%	"	"
240	30%	"	"	30%	"	"	10%	"	"
312	30%	"	"	35%	"	"	10%	"	"
408	30%	"	"	35%	"	"	15%	"	"
576	40%	"	"	50%	"	"	35%	"	"
864	60%	"	"	50%	"	"	35%	"	"
1224	80%	"	"	60%	"	"	70%	"	"

Hours of Exposure	Cadmium Electrodeposition Steel Coupled with Magnesium								
	*Panel Numbers								
	4			6			12		
48	10%	Mg	Corroded	5%	Mg	Corroded	5%	Mg	Corroded
144	10%	"	"	5%	"	"	5%	"	"
240	20%	"	"	10%	"	"	20%	"	"
312	25%	"	"	10%	"	"	20%	"	"
408	40%	"	"	10%	"	"	25%	"	"
576	55%	"	"	25%	"	"	30%	"	"
864	75%	"	"	30%	"	"	40%	"	"
1224	75%	"	"	50%	"	"	60%	"	"

\*These panels are shown in Figure 3.

APPENDIX II  
Table 8

Results of Oxidation-Corrosion Test

Corrosion Medium - Spec. MIL-L-7808 Oil

Test Temperature 347°F. Time 72 Hours

Base Metal - Steel

Coating - Cadmium

<u>Run No.</u>	<u>Wgt. Loss mg./cm<sup>2</sup></u>	<u>Appearance</u>
1	0.024	Stain
2	1.41	Badly Etched Base Metal Ex- posed
3	.048	Stain
4	.048	Stain
5	.176	Etched
6	1.98	Badly Etched Base Metal Ex- posed

Coating - Cd-(73) -Sn-(27) Alloy

<u>Run No.</u>	<u>Wgt. Loss mg./cm<sup>2</sup></u>	<u>Appearance</u>
1	0.016	Stain
2	0.056	Stain
3	0.008	Stain
4	0.025	Stain

These specimens are shown in Figure 4.

APPENDIX II  
Table 9

Results of Corrosion Tests in Jet Fuel (Weight Loss, mg./sq. in)

Test Temperature 95°F.

<u>Days of Exposure</u>	<u>Cadmium Electrodeposit</u>			
	<u>*Panel Numbers</u>			
	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>
3	.35	.40	.60	.40
11	.60	.80	.85	.65
18	.80	1.05	1.15	.90
31	7.45	8.30	7.45	7.95
44	8.75	9.30	8.05	8.90
67	13.85	25.05	9.85	20.30
84	19.45	29.90	21.90	29.40

<u>Days of Exposure</u>	<u>Cd(73%) - Sn(27%) Alloy Electrodeposit</u>			
	<u>*Panel Numbers</u>			
	<u>5</u>	<u>6</u>	<u>7</u>	<u>8</u>
3	.20	.45	.35	.20
11	.35	.55	.45	.50
18	.65	.70	.65	.85
31	.90	.85	.70	.90
44	.30	.25	.70	.80
67	2.30	1.10	2.85	2.00
84	2.75	2.25	3.30	2.20

\*These specimens are shown in Figure 4.

APPENDIX II  
Table 10

Results of Hydrogen Embrittlement Tests

Test Material - 1020 Cold Rolled Wire Dia. .0625"

Control - Untreated Wire

Test No.	Time of Test	Bends to Fracture
1	15.1 Sec.	27
2	13.1 Sec.	23
3	14.7 Sec.	23
4	14.9 Sec.	25
5	18.7 Sec.	27
6	18.8 Sec.	27
7	25.4 Sec.	25
8	17.0 Sec.	27
9	15.9 Sec.	25
10	18.7 Sec.	25
11	46.6 Sec.	25
12	12.2 Sec.	25

Control Value - 25 bends

Cathodically Cleaned for 5 Minutes in Alkaline  
Cleaner at 180°F Using 150 Amps/sq. ft.

Test No.	Bends to Fracture
1	13
2	16
3	17

APPENDIX II  
Table 10 (Cont.)

Anodically Cleaned for 5 Minutes in Alkaline Cleaner at 180°F using 150 amps./sq. ft.

Test No.	Bends to Fracture
1	26
2	27
3	28

\*Anodically Cleaned for 5 Minutes in Alkaline Cleaner at 180°F using 150 amps./sq. ft. and then given a 1 Minute Pickle in a 50% HCl Sol.

Test No.	Bends to Fracture
1	23
2	23
3	24

\*This cleaning cycle was used for all electroplated specimens.

Test No.	Cadmium Plated Wire	
	Plating Thickness	Bends to Fracture
1	.0007"	12
2	.0007"	11
3	.0007"	11

Test No.	Cadmium Plated Wire - 60 Minutes After Plating	
	Plating Thickness	Bends to Fracture
1	.0007"	12
2	.0007"	12
3	.0007"	10

Test No.	Cadmium Plated Wire - Baked at 375°F for 3 Hrs.	
	Plating Thickness	Bends to Fracture
1	.0005"	26
2	.0005"	24
3	.0005"	23

APPENDIX II  
Table 10 (Cont.)

Cadmium-Tin Plated Wire

Test No.	Plating Thickness	Bends to Fracture
1	.0002	24
2	.0002	24
3	.0004	26
4	.0004	26
5	.0005	24
6	.0005	24

APPENDIX II  
Table 11

Results of Hydrogen Embrittlement Tests

Test Material - 1020 Cold Rolled Wire Dia..1235"

Control-Untreated Wire

Test No.	Bends to Fracture
1	20
2	21
3	19
4	19
5	20

Control Value - 20 Bends.

Anodically Cleaned in Alkaline Cleaner for  
5 Minutes at 180°F Using 150 amps. / sq. ft.

Test No.	Bends to Fracture
1	23
2	21
3	22

\*Anodically Cleaned in Alkaline Cleaner for 5 Minutes at 180°F Using  
150 amps. / sq. ft. and then Given a 1 Minute Pickle in a 50% HCl Sol.

Test No.	Bends to Fracture
1	20
2	21
3	22

\*This cleaning cycle was used for all electroplated specimens.

APPENDIX II  
Table 11 (Cont.)

Cadmium Plated Wire

Test No.	Plating Thickness	Bends to Fracture
1	.0004"	15
2	.0004"	14
3	.0004"	15

Tin Plated Wire

Test No.	Plating Thickness	Bends to Fracture
1	.0001"	20
2	.0001"	18
3	.0001"	20

Cadmium-Tin Alloy Plated Wire

Test No.	Plating Thickness	Bends to Fracture
1	.0003"	21
2	.0003"	20
3	.0003"	20



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